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# Guidelines for Identifying New Baryon Resonances

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# Introduction

I will skip any remarks about *why* one might want to look for new baryon resonances. Hopefully that is obvious to anyone attending this conference. Instead I will discuss my biased views on good (*i.e.*, "convincing") and not-so-good ways of finding new baryon resonances.

# Discussion

I'll open by commenting on a recent case. One well-known example is the bump seen in the SAPHIR data for $\sigma(\gamma p \to K^+\Lambda)$, which has been interpreted as evidence for a $D_{13}(1960)$.

[See "Evidence for a missing nucleon resonance in kaon photoproduction," by T. Mart and C. Bennhold, Phys. Rev. C **61**, 012201-1 (2000).]

## What is the evidence for this interpretation?

- Structure in the total cross section cannot be reproduced by isobar-model calculations that include only $S_{11}(1650)$, $P_{11}(1710)$, and $P_{13}(1720)$.
- Only the $D_{13}(2080)$ has been identified in older $\pi^- p \to K^0 \Lambda$ analyses as having a noticeable $K\Lambda$ branching ratio.
- According to Mart and Bennhold, the constituent quark model of Capstick and Roberts predicts only four states around 1900 MeV with a significant $K\Lambda$ decay width. These are the model states $S_{11}(1945)$, $P_{11}(1975)$, $P_{13}(1950)$, and $D_{13}(1960)$. However, only the $D_{13}(1960)$ is predicted to have significant photocouplings.

Mart and Bennhold admit that *all four of the above states can reproduce the data* if the mass, width, and coupling constants of the resonance are allowed to vary.

Because of a limitation of their model, Mart and Bennhold were unable to investigate whether resonances in higher-spin partial waves, such as $D_{15}$, could also reproduce the data. Indeed, Capstick and Roberts predict that the model state $D_{15}(2080)$ *also* has a noticeable $K\Lambda$ decay. The predicted coupling is consistent with that identified for the $D_{15}(2200)$ in older $\pi^- p \to K^0\Lambda$ analyses. This state is predicted to have a sufficiently large photocoupling to contribute noticeably in $\gamma p \to K^+\Lambda$.

The *experimental identification* of the structure in $\gamma p \to K^+\Lambda$ as due to a $D_{13}(1960)$ resonance suffers from a problem with *uniqueness.* It seem likely to me that more than one resonance contributes to the structure. (For example, it is well known that for $\pi N$ elastic scattering, three resonances contribute in the second resonance region and several contribute in the third and fourth regions.)

In order to determine experimentally which resonance dominates $\gamma p \to K^+\Lambda$ and how many resonances contribute to the structure near 1900 MeV, one needs to be able to carry out a full partial-wave analysis.

It is my opinion that the *only* unambiguous way to identify a new baryon resonance is by first carrying out a partial-wave analysis. In other words, it is not enough to just vary a few parameters in some model of a reaction in order to describe a bump in a cross section.

Following Gerhard Höhler, I believe that a good method to identify resonances (new or old) is by studying the peaks of speed plots (what I like to call "speed bumps"). The speed of a T-matrix amplitude is defined as

$$\text{speed}(W) = \left|\frac{dT}{dW}\right| , \tag{1}$$

where $W$ is the total c.m. energy.

It is an almost model-independent result that the centroid of a peak in a speed plot is given by $M$ and the FWHM is given by $\Gamma$, where the pole position of a resonance is $M - i\Gamma/2$. The height $H$ of the peak in the speed plot provides "almost model-independent information on the magnitude of the resonance signal".

The following speed plots show evidence for some new or poorly established resonances. However, based on these speed plots, there is little direct evidence for some so-called established resonances, such as $D_{13}(1700)$.

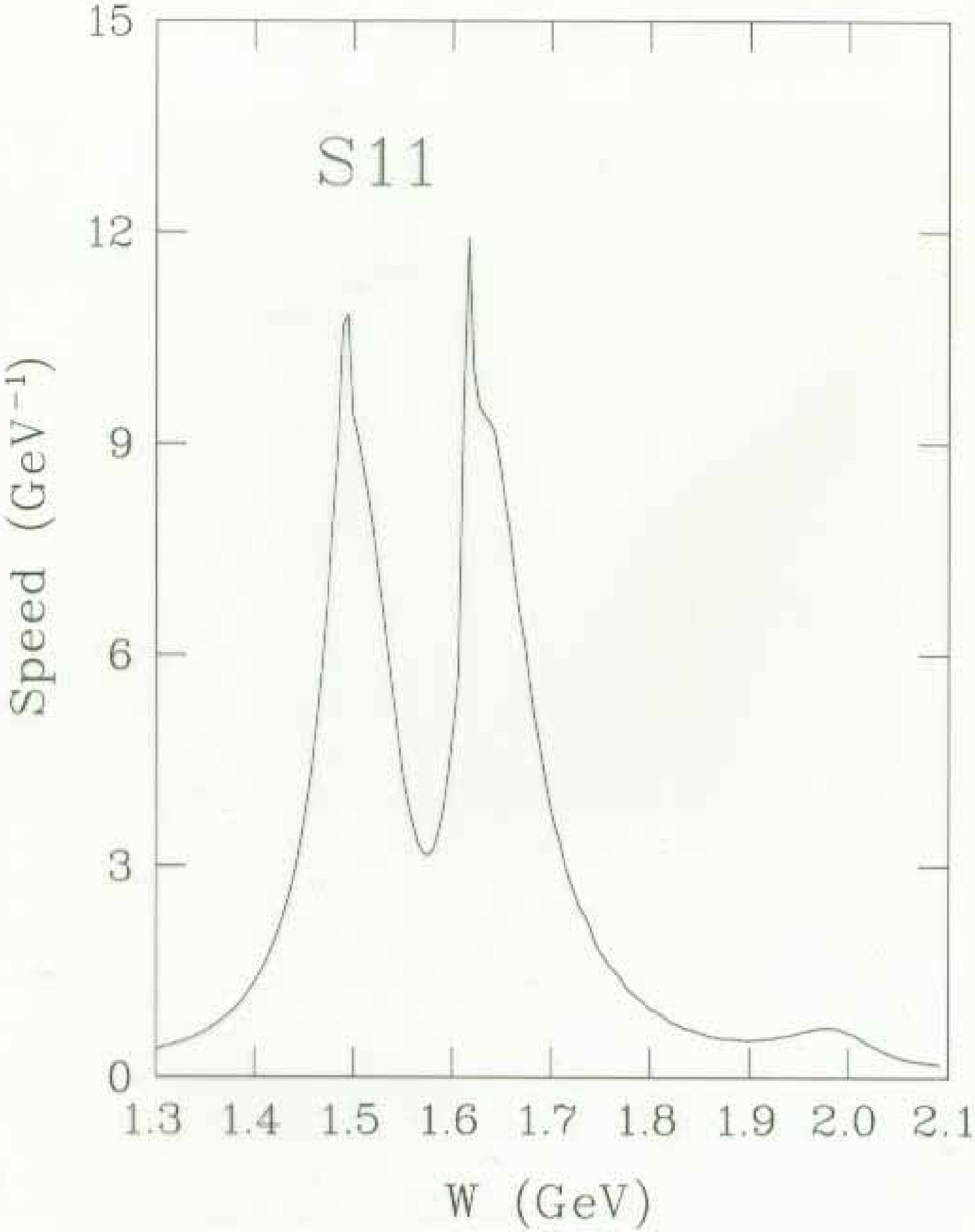


Figure 1: Speed plot for $S_{11}$ $\pi N \rightarrow \pi N$ amplitude.

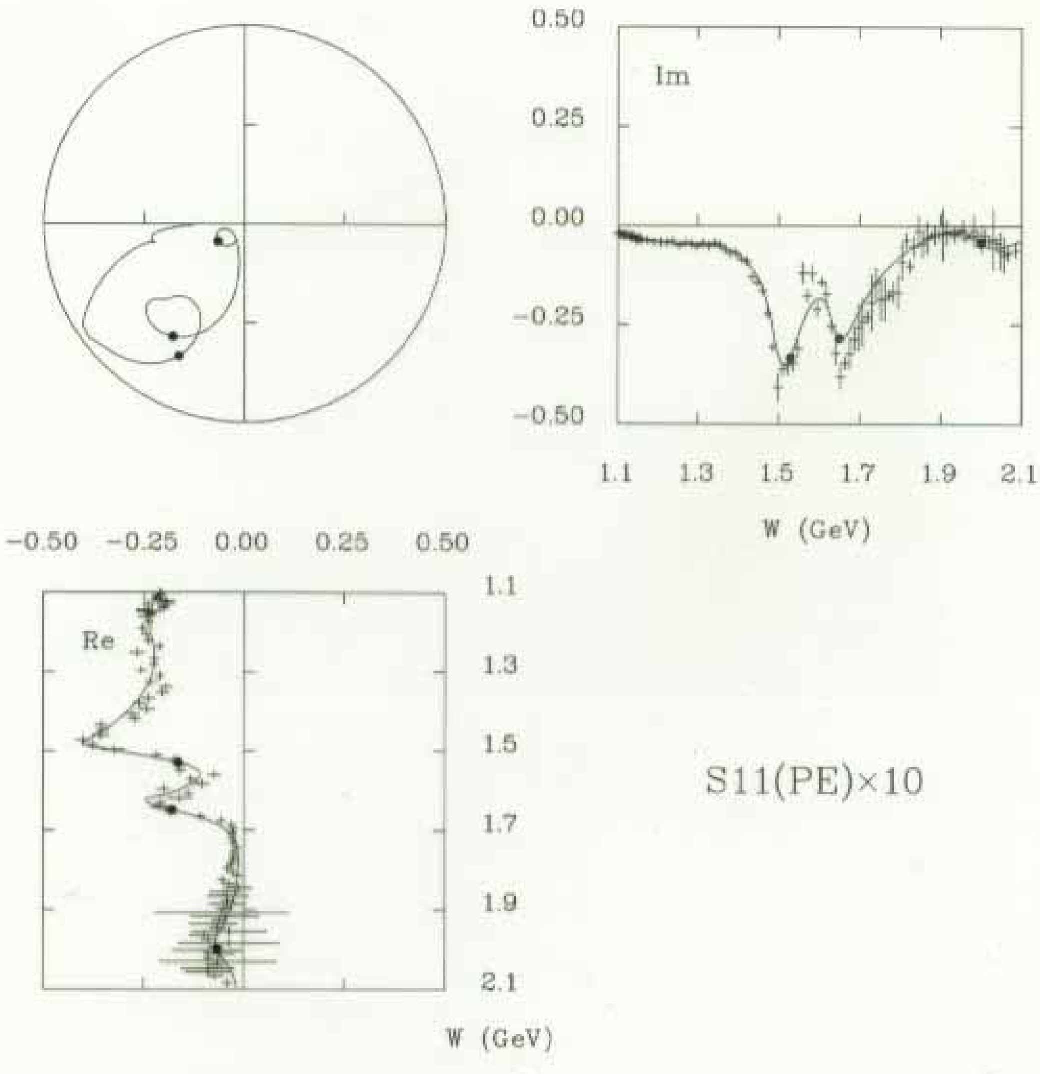


Figure 2: Argand diagram for $S_{11}$ $\gamma p \to \pi N$ amplitude.

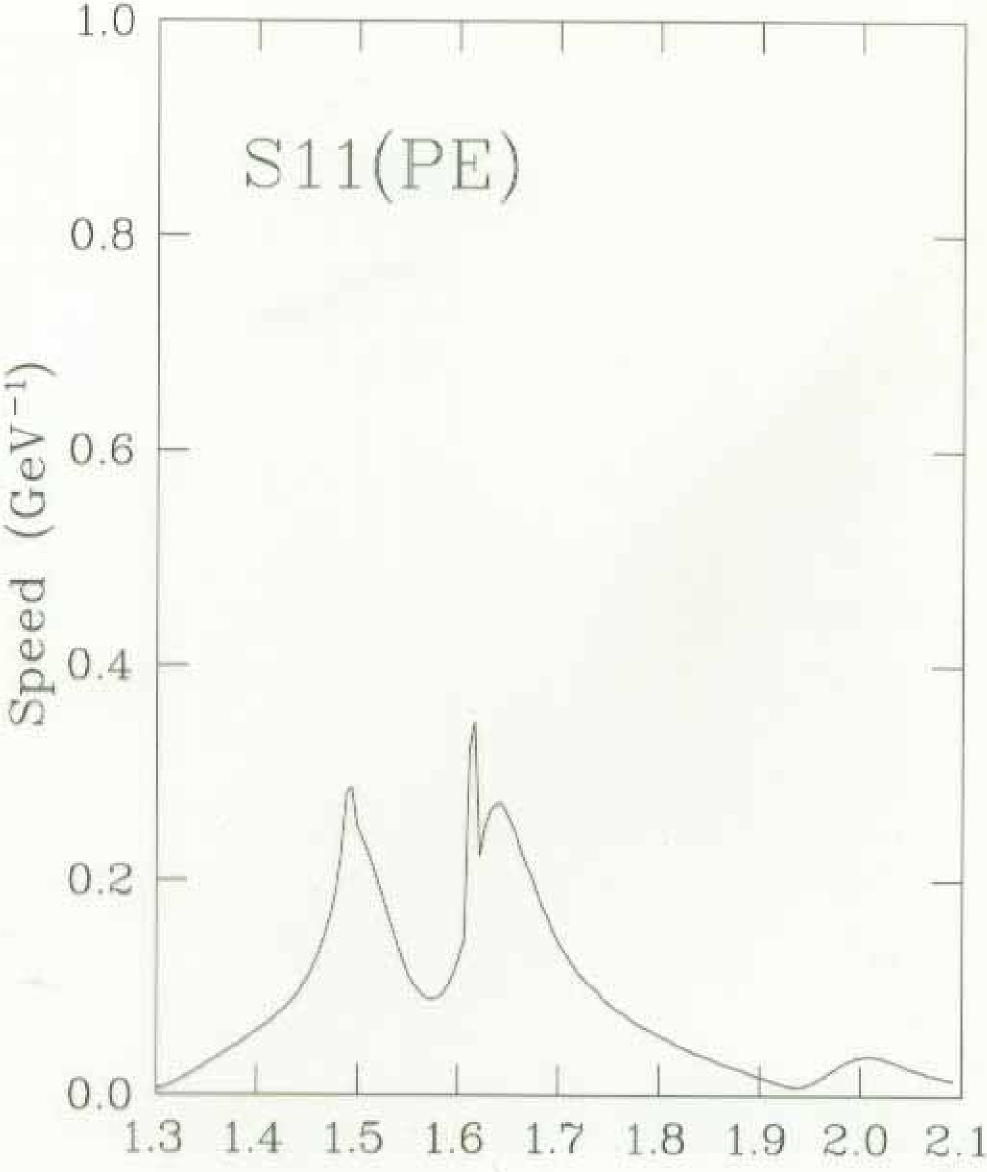


Figure 3: Speed plot for $S_{11}$ $\gamma p \to \pi N$ amplitude.

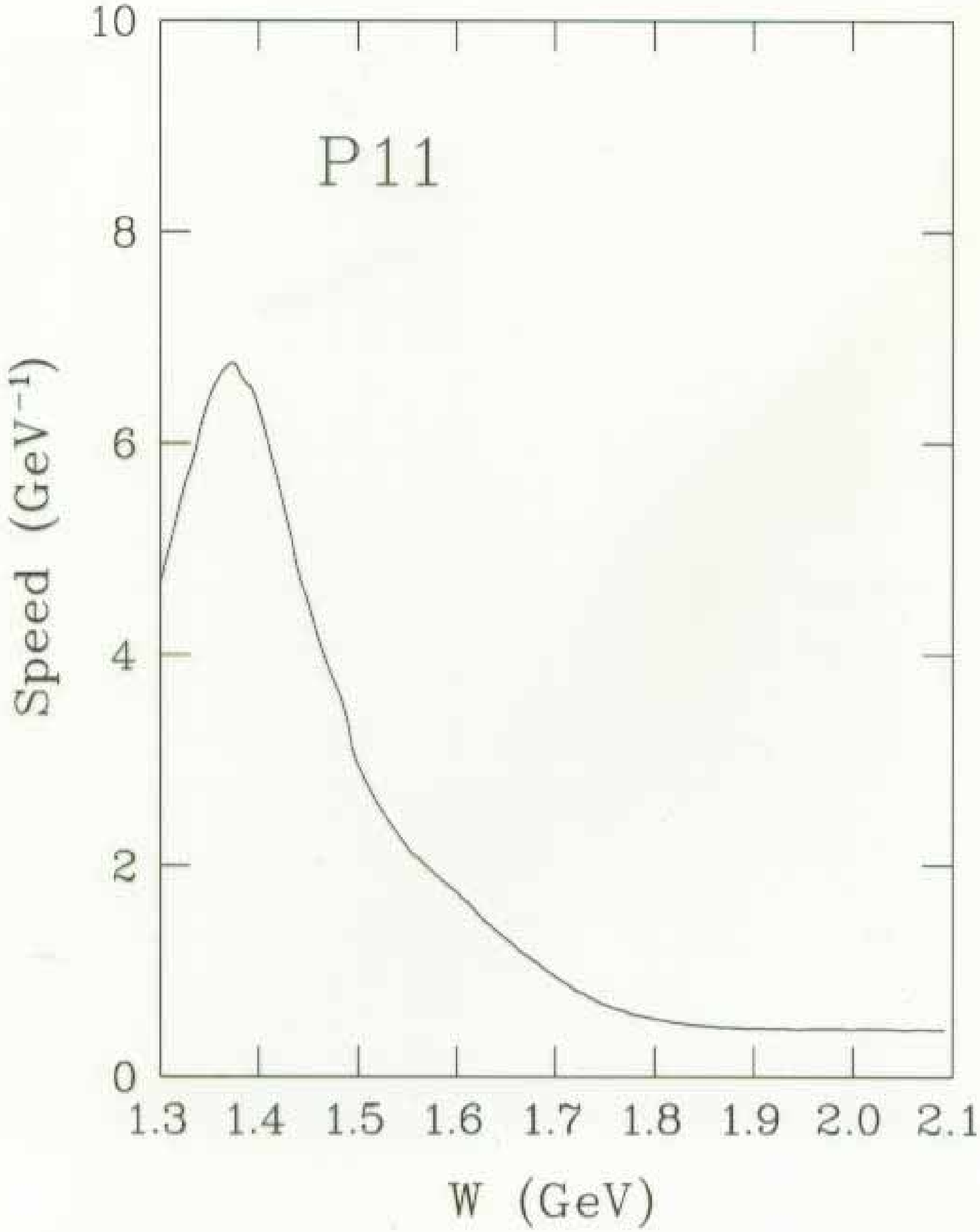


Figure 4: Speed plot for $P_{11}$ $\pi N \to \pi N$ amplitude.

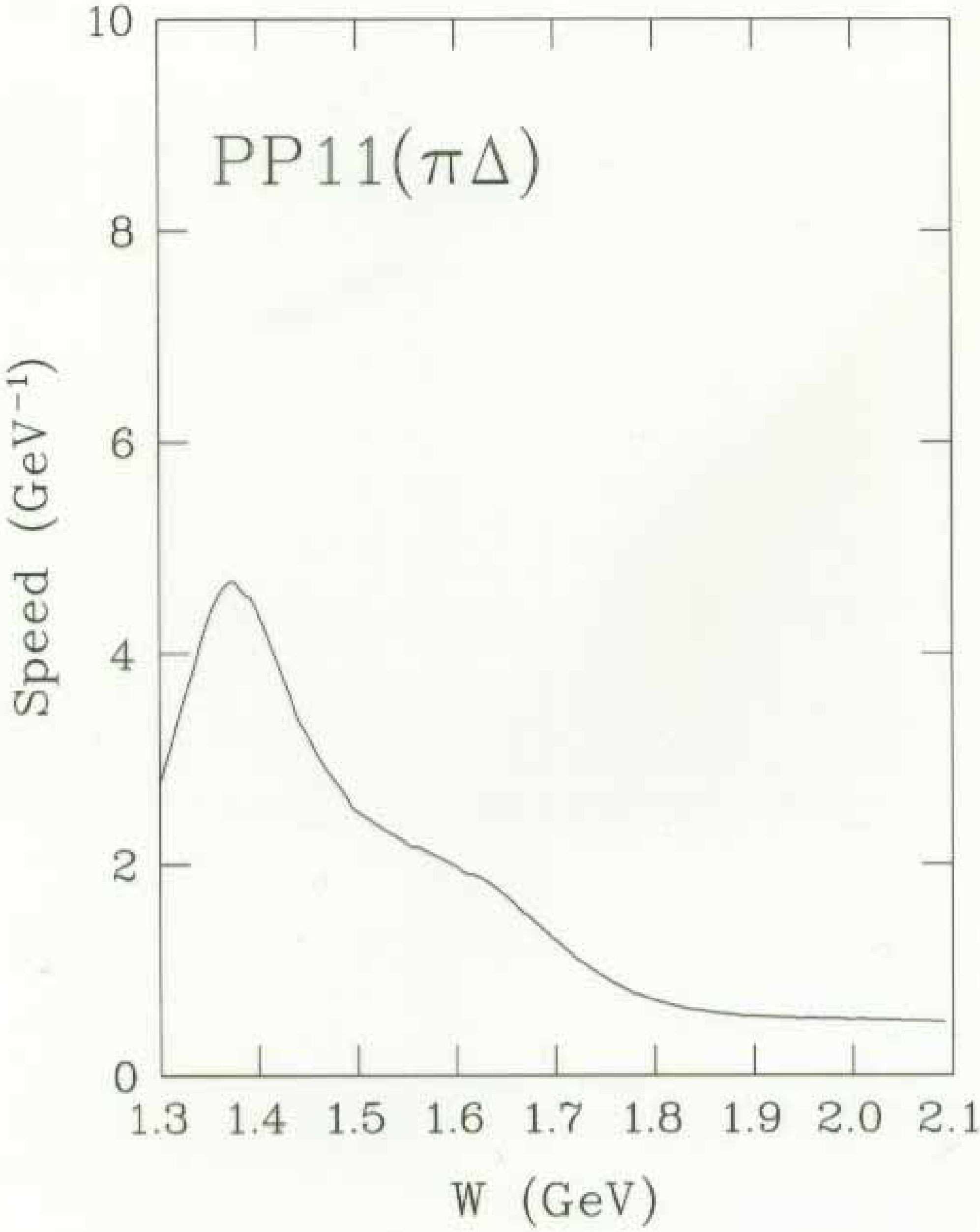


Figure 5: Speed plot for PP11 $\pi N \rightarrow \pi\Delta$ amplitude.

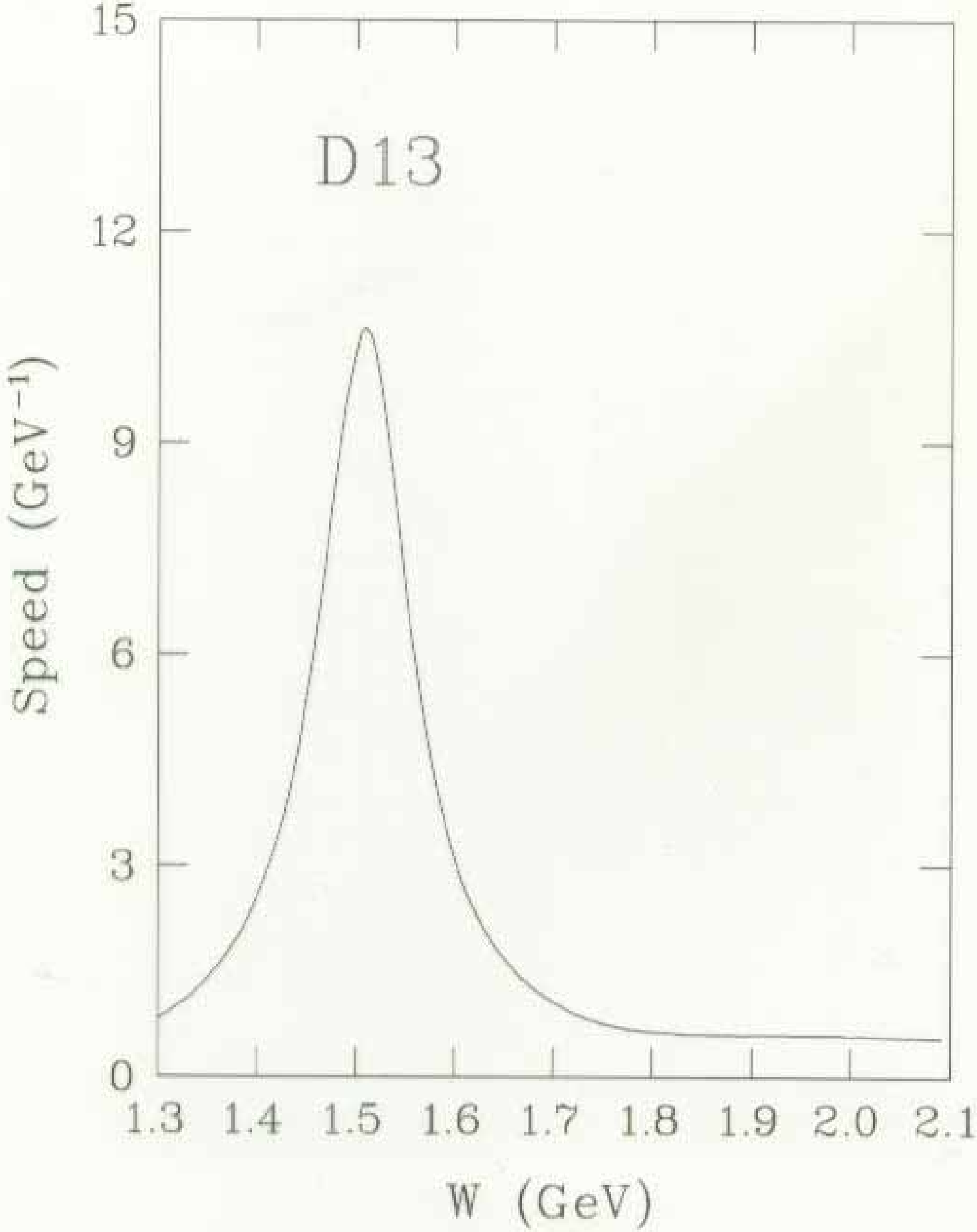


Figure 6: Speed plot for $D_{13}$ $\pi N \to \pi N$ amplitude.

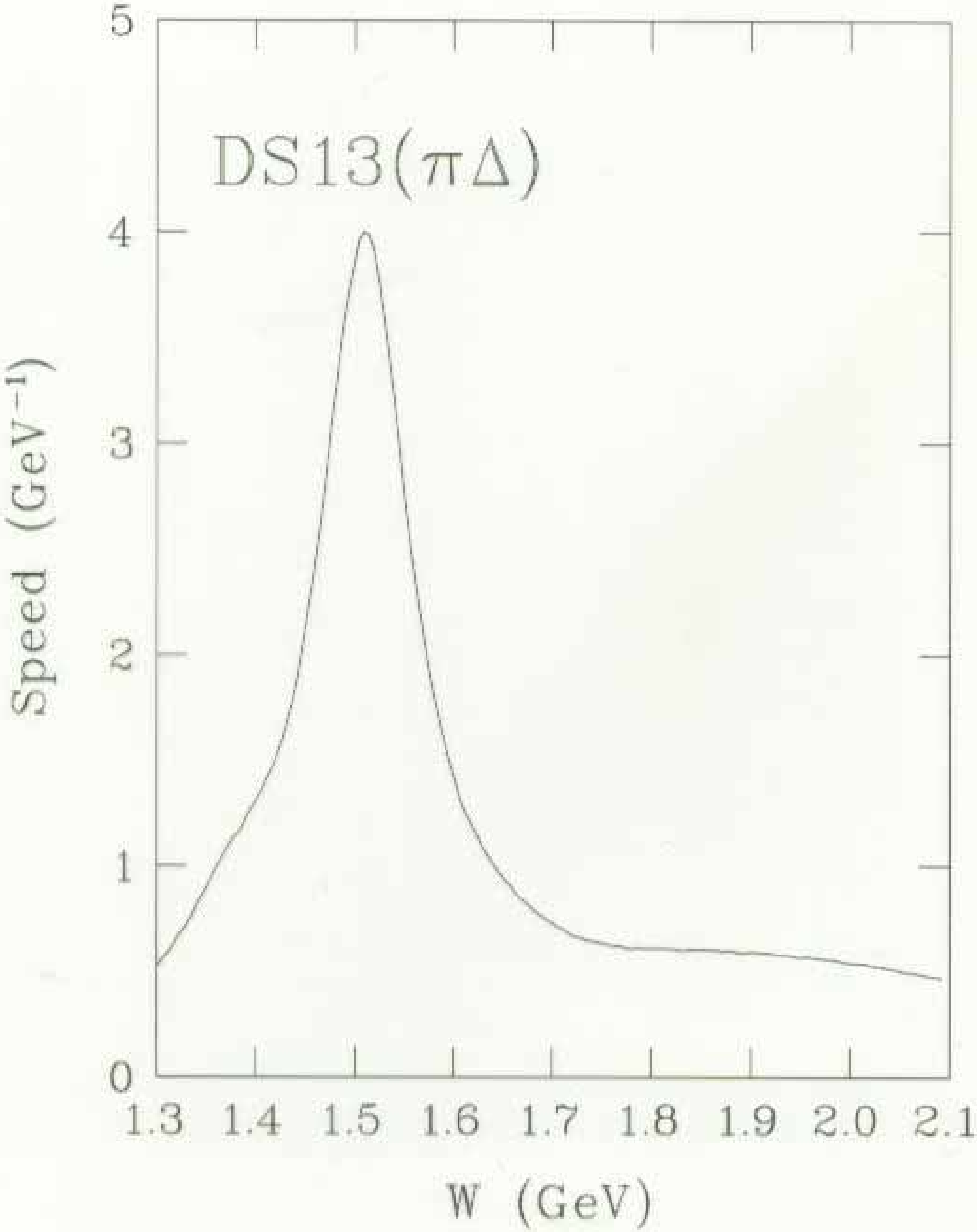

Figure 7: Speed plot for DS13 $\pi N \to \pi\Delta$ amplitude.

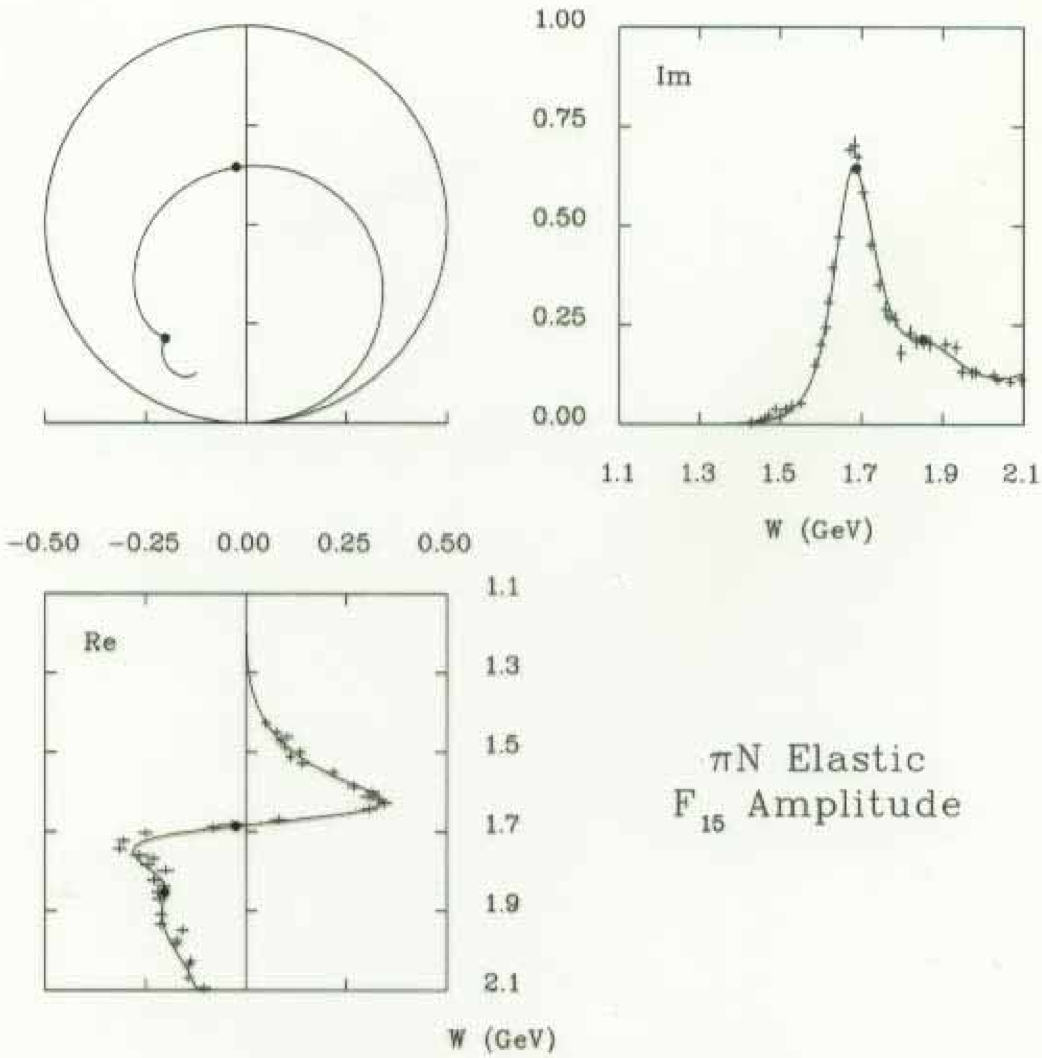


Figure 8: Argand diagram for $F_{15}$ $\pi N \to \pi N$ amplitude.

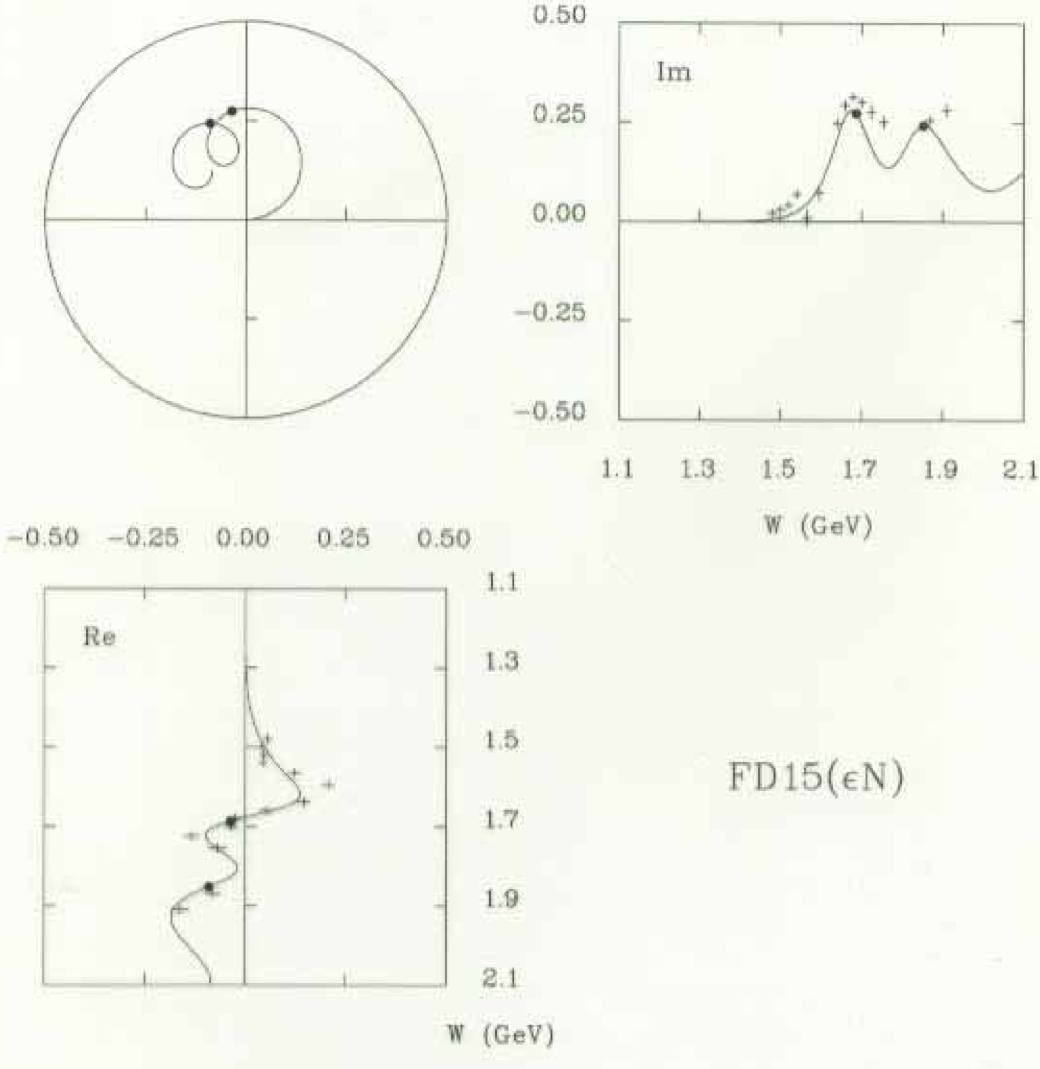


Figure 9: Argand diagram for FD15 $\pi N \rightarrow \epsilon N$ amplitude.

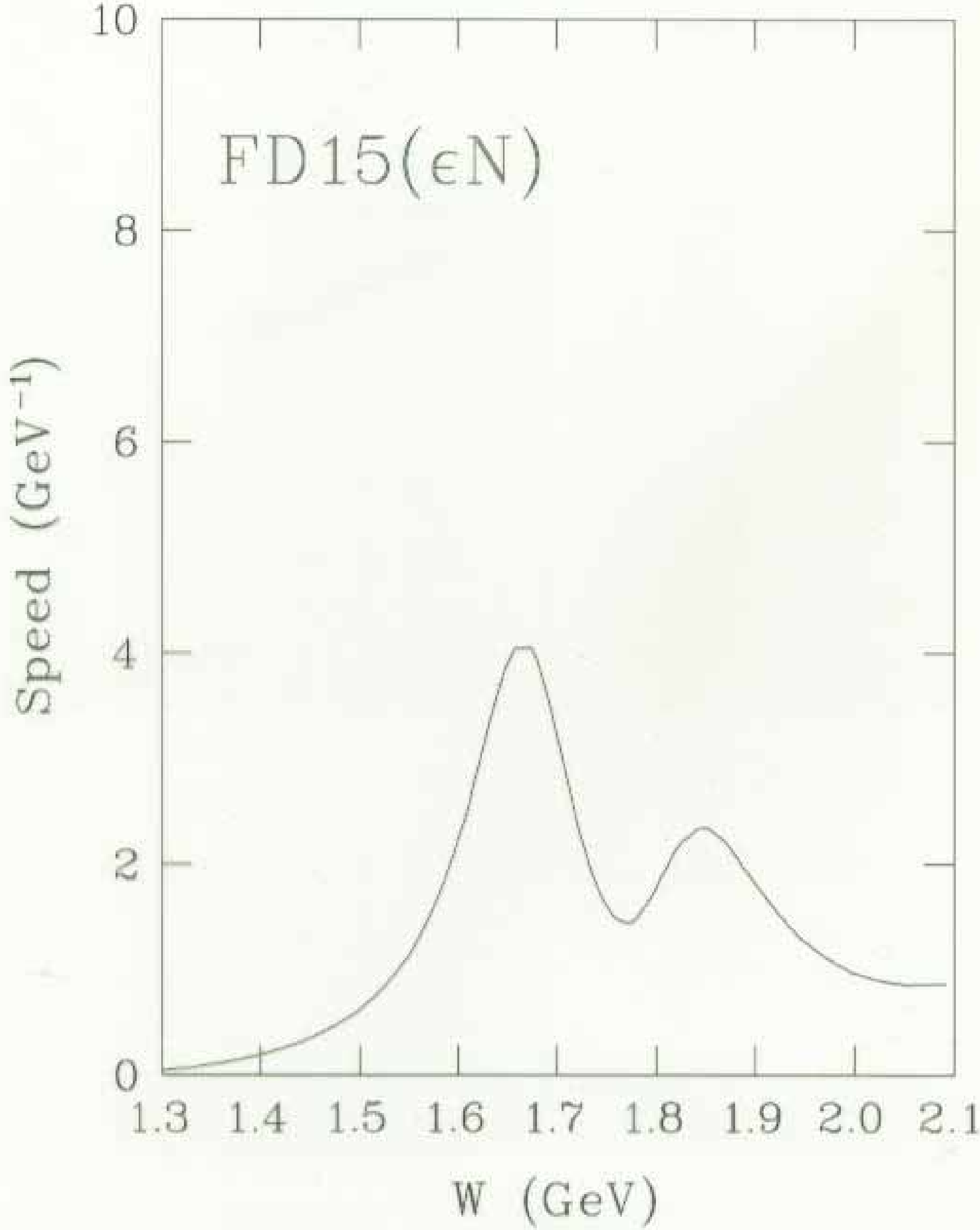


Figure 10: Speed plot for FD15 $\pi N \to \epsilon N$ amplitude.

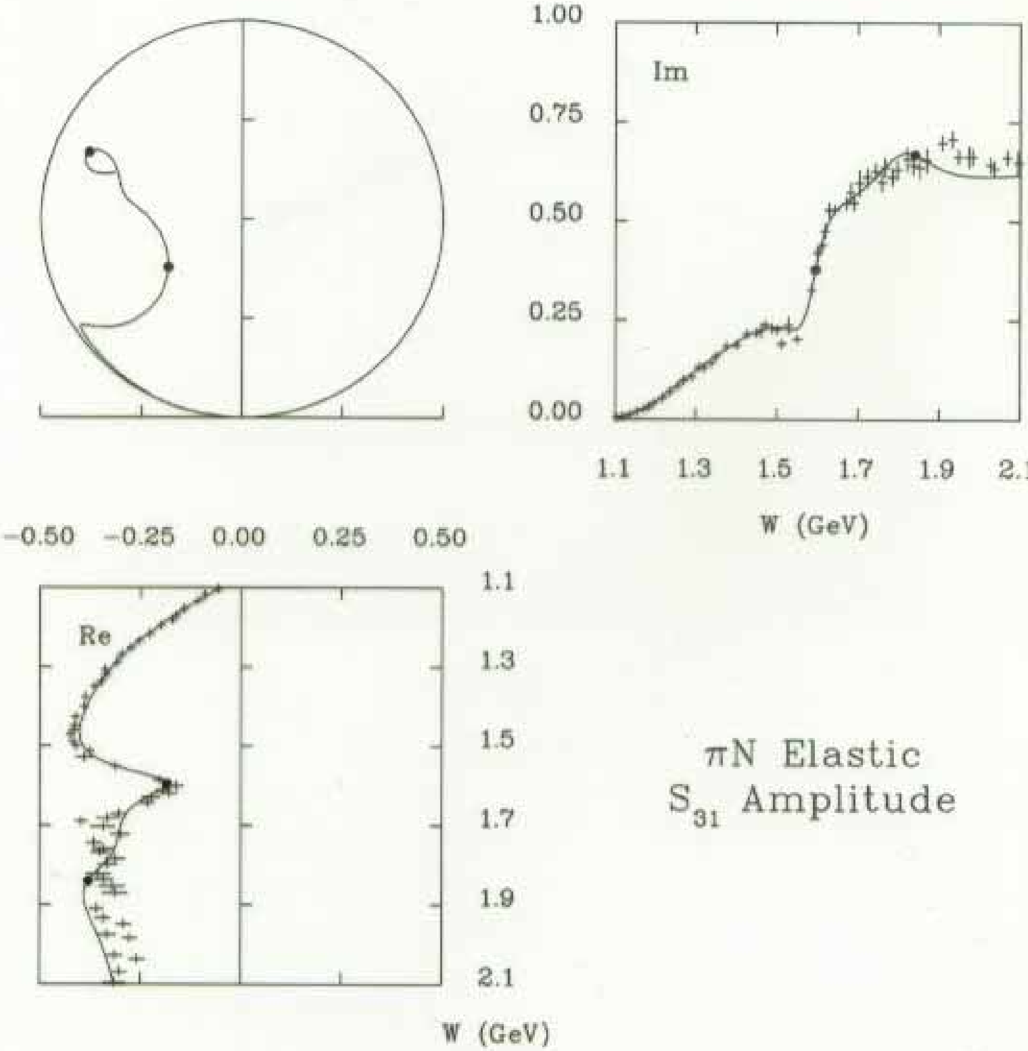


Figure 11: Argand diagram for $S_{31}$ $\pi N \to \pi N$ amplitude.

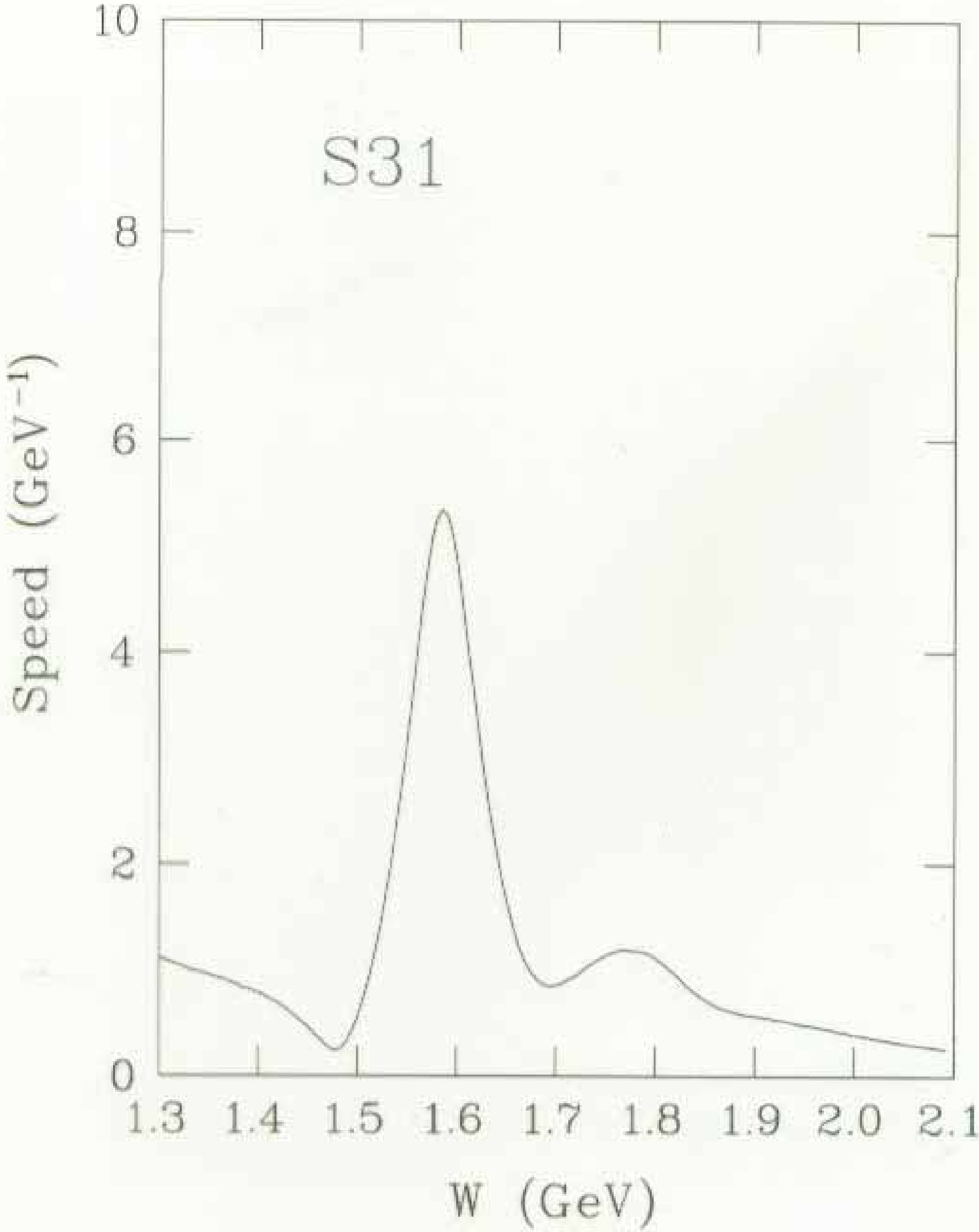


Figure 12: Speed plot for $S_{31}$ $\pi N \rightarrow \pi N$ amplitude.

## Summary and Recommendations

- New hadronic data above the second resonance region are unlikely to be forthcoming,* so we must do the best possible job analyzing (or re-analyzing) the existent hadronic data. This means, for example, performing multichannel fits to describe several resonance reactions consistently.

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*The Crystal Ball Collaboration will provide new data for $\pi^- p \to \pi^0 n$, $\pi^0 \pi^0 n$, $\eta n$ in the first and second resonance regions.

- The new JLab data for $\gamma p \to \pi N$ need to be analyzed and published as soon as possible. These and the data for $\pi N \to \pi N$ will furnish the *foundation* for analyzing other meson photoproduction (and electroproduction) data, including for $\gamma N \to \pi\pi N$, $\eta N$, $K\Lambda$, *etc.*

- We need to measure high statistics data over small energy bins for as many different resonance reactions as possible. We need to look at new reactions (*e.g.*, $\gamma p \to \eta\Delta$, $\gamma p \to \omega\Delta$) and at old reactions in different ways (*e.g.*, using spin observables or extending measurements to higher energies).

- Convincing results (as opposed to merely suggestive ones) for new baryon states will require *partial-wave analyses* to sort out the quantum numbers of resonances unambiguously, and *coupled-channel partial-wave analyses* to resolve overlapping states in individual waves.
- Finally, we should be guided by quark-model predictions, but not be blinded by theoretical biases. We should avoid doing "bump science". *I.e.*, we should approach our work as physicists, not as *phrenologists*. (Phrenology is the occult practice of trying to understand a person's character by "reading bumps" on their skull.)